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FACTOR ANALYSIS ON SAFETY AWARENESS IN UNIVERSITY RESEARCH LABORATORIES IN JAPAN

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ABSTRACT

This study reports on analysis of safety awareness in scientific university research laboratories in Japan by Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). In order to reveal safety in the laboratories, which is considered significantly important but is treated empirically and ambiguously, this study explored the subconscious views of laboratory researchers through a questionnaire method. The questionnaire survey was targeted at science-major students in universities and professional training college in Japan. By EFA and CFA, statistical analysis was observed on 406 obtained samples. From EFA, four factors were extracted: "Education and cooperative structure on safety", "Operational procedures", "Self protection", and "Sense of fulfillment". A result of EFA indicated a hypothetical construct that the answers of the questionnaire items should be represented by the factors and additional unexpected factors in a given domain of questions. When additional contributions of the factors showed relatively higher factor loading to the items in EFA are considered, this construct can indicates a good fit in CFA. EFA also revealed that the relationships among the safety awareness and the latent factors. It showed that safety awareness in universities seems to have close to safety education and that in scientific research laboratories seems to be recognized by laboratory-near-affairs. The factors derived from factor analysis are expected to help in comprehending the examinees' recognition and understanding of safety as well as explaining their safety behavior.

Keywords: Factor analysis, laboratory safety, Japanese university, research laboratory, questionnaire, safety awareness

1. INTRODUCTION

Exploratory Factor Analysis (EFA) is one of the multivariate data analyses used for uncovering factors that constitute features of a scientific research laboratory such as individual characteristics or behavioral features. EFA is particularly useful with multi-item inventories designed to measure personality, attitudes, behavioral styles, cognitive schema and other multifaceted constructs of interest to clinical psychologists (Floyd, 1995). Since its initial development about a century ago (Spearman, 1904, 1927), EFA has been one of the most widely used statistical procedures not only in the psychology field but also in the fields of behavioral science and biology.

One feature of EFA is to reveal behaviors based on the subconscious. Lavie and Tractinsky (2004) reported the results of assessing the dimensions of perceived visual aesthetics of a website. The purpose of the study was to explain the concept of perceived visual aesthetics and to find methods for measuring it. Two factors were extracted by this analysis: “classical aesthetics” which represents traditional notions of aesthetics (e.g. “well organized,” “clear,” “clean,” and “symmetrical“), and “expressive aesthetics” which represents qualities that go beyond classical principles and that stresses the designer’s creativity and expressive power (e.g. “originality,” “fascinating design,” and “use of special effects”). In another study, Frasure-Smith and Lesperance (2003) noted the psychological risks for which importance had not yet been revealed in the prognosis after a cardiac disease. By using a self-report method, the study examined the relative importance of depression, anxiety, anger, and social support in predicting 5-year cardiac-related mortality following a myocardial infarction and assessed the role of any common underlying dimensions. The extracted underlying factors were “negative affectivity”, “overt anger”, and “social support”. Hence, by statistical processing, EFA is utilized to discover the latent variables that underlie any scale.

On the other hand, the importance of subconscious influences on behavior regarding safety in scientific university laboratories has recently been recognized. Feisel & Rosa (2005) noted that teaching laboratories in engineering departments provide opportunities to develop within three domains of engineering education: cognitive, psychomotor, and affective. Laboratory safety affects all three domains. Wu (2008) reported that among faculty in the teaching laboratories of electric and electronic engineering departments in Taiwanese universities, the perception of safety leadership of department head was positive. The leadership of these department heads is composed mainly of three factors: safety controlling, safety coaching, and safety caring. In addition, Shaftel and Shaftel (2005) reported that the influence of teaching on knowledge and skill development is well understood at universities, but that much less is known about the influence of effective education on student attitude and behavior. Therefore, what individuals know may influence their attitude about the topic, and how they feel about that topic may influence their behavior (Schrader and Lawless, 2004)

Although these studies suggested that awareness of experimentalists could be a vital part of laboratory safety in teaching laboratories which undergraduate students do the same experimental topic, no study on this issue has been reported for research laboratories where students and researchers work on their own research topics.

In the present study, factor analysis which is broadly used for statistical analysis was applied to safety in university research laboratories. This study focused on subconscious thoughts on safety that are considered to be only vaguely understood. By applying a statistical method to questionnaire results, the goals of this study are to investigate factors that compose of safety awareness and to contribute to a better understanding of safe behavior in research laboratories.

2. MATERIALS AND METHOD

2.1 Survey instrument

This survey was carried out using a multiple-choice questionnaire method. The questionnaire items were designed to ask about matters regarding safety in university laboratories such as safety management, safety training, accidents, and environment and safety. Subjects rated items were using a 5-point scale: agree, somewhat agree, neutral, somewhat disagree, and disagree. The respondents ticked the answer that corresponded best with their feelings about the statement given. A score of 1-5 was assigned to each of these responses. The respondents were also asked about gender, academic field, length of experience in the current field of study, and frequency of laboratory use as personal information.

Three experts were invited to assess the contents of this questionnaire. The questionnaire items were examined by the experts to confirm item clarity and conciseness of expression, and their appropriateness for the purpose of this study.

2.2 Sampling and data collection

First, a pilot test was carried out to verify the adequacy of data interpretation of the research instrument. The sample for the pilot test was selected from science major courses at public universities. The obtained total number of answers was 58. After items that showed ceiling/floor effect and/or low factor loading (< 0.3) were removed throughout this instrument, 19 items remained (Table 1).

Table 1 Instrument items used in questionnaire sheet

No.	Questionnaire items
Q1	My university focuses on environmental health and safety of students doing experiments.
Q2	My laboratory is conscious of environmental health and safety.
Q3	My laboratory establishes opportunities (i.e. seminar) to discuss EHS issues for experiments.
Q4	My laboratory has a consultation system in place to discuss my experiments.
Q5	The environment in which I conduct my experiments is safe.
Q6	What I learned in the training system is useful for my research.
Q7	I wear safety glasses.
Q8	I use in a fume hood when using chemical substances.
Q9	I wear a lab coat/protective clothing during experiments.
Q10	Usage manuals have been created for our laboratory equipment.
Q11	Emergency closing operations have been determined for our laboratory equipment.
Q12	I know the emergency contact information for the professors in charge of my laboratory.
Q13	I understand the procedures for performing experiments at night and at weekends.
Q14	I experiment at night by myself.
Q15	I do not eat/drink anything in the laboratory.
Q16	I keep the area around me clean and organized.
Q17	I understand the procedure for handling accidents or injures that occur during experiments.
Q18	I consider the possibility of accidents before starting an experiment.
Q19	My lab and/or school conducts sufficient training for accident prevention.

After the pilot test, the formal test sample was selected from science-major students at seven schools (including universities and professional training college) in Japan: Ehime University, Kumamoto University, Kyoto University, Osaka University, The University of Tokyo, Toyama Prefectural University, and Toyama National College of Technology. The questionnaire was distributed to students who belonged to a scientific research laboratory in October 2008. The sheets were first handed to or mailed to the faculty/staff in charge of environmental safety issues at each school, then distributed to the students through their formal organizational network. All sheets submitted to each faculty/staff were returned to us and used in this analysis.

2.3 Data analysis

The questionnaires were submitted by the faculty/staff at each university or scientific research laboratory, and then returned by mail. Total number of obtained responses was 406. The data was deemed appropriate for the analysis if the case-to-variable ratio was above the minimum requirement of 5:1 (Hair et al., 1995). The ratio was 406 cases (the number of samples) to 19 variables (the number of questionnaire items), so that this study could meet the minimum requirement. Table 2 summarized the respondents' affiliation in gender, academic fields, length of experience in the current field of study, and frequency of laboratory use. Since we asked faculty/staff at seven schools to distribute questionnaire sheets as much as possible, the quantity of responses in gender, academic field, length of experience in the current field of study, and frequency of laboratory use varied greatly.

Table 2 Sample features

	N	%
Gender		
Male	298	73.6
Female	107	26.4
Total	405*	100.0
Academic Field		
Chemistry	218	53.7
Biology	137	33.7
Medicine	13	3.2
Mechanics	26	6.4
Electronics	5	1.2
Other	7	1.7
Total	406	100.0
Length of experience in the current field of study		
1 year	167	41.5
2 year	107	26.6
3 year	106	26.4
4 year	16	4.0
5 year	6	1.5
Total	402*	100.0
Frequency of Lab usage		
Almost everyday	359	89.1
Several times a week	35	8.7
Several times a month	7	1.7
Several times a year	1	0.2
Never	1	0.2
Total	403*	100.0

* There were several unmarked respondents.

3. RESULTS AND DISCUSSION

3.1 Exploratory factor analysis

In order to reveal subconscious thoughts on safety which are considered to be only vaguely understood, questionnaire items asking about an issue related to safety in universities and scientific research laboratories were created. Statistical treatment of batches of the questions should provides factors that construct safety awareness in universities and scientific research laboratories. If the extracted factors represent safety awareness, these items asking about safety awareness itself should be comprehended by the factors as well when properly analyzed statistically. From this estimation, the following two-step approach was taken: 1) latent factors (hypothesized and unobservable concept that can be represented observable or measurable values) of safety awareness were explored by EFA, and 2) relationship between the factors and the items directly asking about safety awareness were examined by correlation analysis.

PASW SPSS statistics 17.0 was used for EFA, and the Principal Factor Method (PFM) was applied to this study. Because of its effectiveness in factor extraction to maximize the variance explained for each factor, determined in order of increasing factor number.

The analysis resulted in the ceiling/floor effect upon 5 items. The items which showed a ceiling effect were "**Q12:** I know the emergency contact information for the professor in charge of my laboratory", "**Q7:** I wear safety glasses", "**Q13:** I understand the procedure for performing experiments at night and at weekends" and "**Q17:** I understand the procedure for handling accidents or injures that occur during experiments". On the other hand, the item which showed a floor tendency was "**Q15:** I do not drink/eat in the laboratory". These items were eliminated from the questionnaire items at EFA. In addition, the 2 items asking about safety awareness in university or scientific research laboratory (**Q1** and **Q2**) were excluded in EFA because the items were used for correlation analysis in section 3.4.

A promax rotation was performed to enhance factor interpretability. Items that failed to attain correlations of 0.3 or above with any other item were omitted initially. By the obtained scree plot, 4 factors were extracted with an eigen value of greater than 1 which explained 34.7% of the total variance were determined. There was a total of 12 items on the scale.

The promax-rotated factor pattern implied the first factor concerned "Education and cooperative structure on safety" (5 items, $\alpha = 0.656$). This factor is comprised of "**Q14:** My lab and/or school conducts sufficient training for accident prevention" and "**Q3:** My scientific research laboratory establishes opportunities (i.e. seminars) to discuss EHS issues for experiments". The second factor concerned "Operational procedures" (2 items, $\alpha = 0.629$). This was comprised of "**Q11:** Emergency closing operations have been determined for our laboratory equipment", and "**Q10:** Usage manuals have been created for our laboratory equipment". The third concerned "Self protection" (3 items, $\alpha = 0.435$). This was comprised of "**Q9:** I wear a lab coat/protective clothing during experiments", and "**Q8:** I use a fume hood when using chemical substances". The fourth concerned "Sense of fulfillment" (2 items, $\alpha = 0.254$). The 4 factors with their names, the items in each factor, their factor loadings, explained variance, and reliability coefficients are summarized in Table 3.

Table 3 The four extracted factors in EFA

Label and items	Factor			
	1	2	3	4
Factor 1 - Education and cooperative structure on safety				
Q19 My laboratory and/or school conducts sufficient training for accident prevention.	**.680**	.007	-.057	-.109
Q3 My laboratory establishes opportunities (i.e. seminar) to discuss EHS issues for experiments.	**.643**	-.017	-.094	-.128
Q4 My group has a consultation system in place to discuss my experiments.	**.638**	.042	-.032	.027
Q6 What I learned in the training system is useful for my research.	**.465**	-.037	.098	-.077
Q18 I consider the possibility of accidents before starting an experiment.	**.374**	.073	.101	-.176
Factor 2 – Operational procedures				
Q11 Emergency closing operations have been determined for our laboratory equipment.	-.040	**.805**	.018	-.021
Q10 Usage manuals have been created for our laboratory equipment.	.080	**.531**	-.018	.035
Factor 3 – Self protection				
Q9 I wear a lab coat/protective clothing during experiments.	-.049	-.034	**.639**	-.135
Q8 I use in a fume hood when using chemical substances.	-.016	.272	**.342**	.012
Q16 I keep the area around me clean and organized.	.276	-.068	**.340**	.283
Factor 4 - Sense of fulfillment				
Q14 I experiment at night by myself.	-.291	-.013	-.048	**.496**
Q5 The environment in which I conduct my experiments is safe.	.265	.058	-.121	**.482**
Variance explained	20.8	6.44	4.18	3.18
Reliability coefficients	.656	.629	.435	.259

3.2 Reliability and Validity of the instrument

A factor in a questionnaire generally has high factor loading to some questionnaire items. Therefore, questionnaire items which are strongly influenced by the same factor should show a similar tendency in answers. Out of the various methods used for measuring reliability, the internal consistency method is considered to be the most effective method (Cronbach, 1951). The internal-scale reliability (Cronbach's Alpha; α) of the scale was estimated as 0.75 which is above the acceptable minimum limit of 0.6 (Hair et al., 1995). The reliability coefficients across items in two factors were found to be above 0.6. The other two coefficients had lower values: 0.44 and 0.25. The low-value-coefficient could be explained by the fact that the items categorized into these two factors showed relatively high factor loading at two or three factors. For example, the item "**Q16:** I keep the area around me clean and organized" was influenced mainly by the factor; "Self protection" (0.340), and additionally by the factors; "Sense of fulfillment" (0.283) and "Education and cooperative structure on safety" (0.276).

The measure of sampling adequacy (Kaiser-Meyer-Olkin; KMO measure) was 0.77, which demonstrates that factor analysis is appropriate for this data (Kaiser, 1974, Kaiser 1970). Bartlett's Test Sphericity was significant for the test ($\chi^2 = 607.68$, df = 66, $p < 0.000$), which shows that correlations exist among the items.

3.3 Confirmatory factor analysis

In contrast to pure exploration of factors in EFA, Confirmatory Factor Analysis (CFA) was conducted on the sample in this study. CFA is primarily a method for assessing the construct validity of measures and is frequently used to verify a priori hypotheses. The hypothetic model is typically described as some of the expected constructs perhaps along with additional unexpected factors. Construct validity is supported if the factor structure of the scale is consistent with the constructs that the instrument purpose to measure. If factor analysis fails to detect underlying constructs that explain sufficient variance in the measured variables or if the constructs detected are inconsistent with expectations, the construct validity of the scale is compromised.

In this current study, CFA was used to test the adequacy of a model derived from the EFA and to verify the structure of safety awareness. AMOS version 18 was utilized to conduct CFA. CFA was conducted on the model composed of 4 latent variables, 12 observed variables and 12 error variables (The structure of the model is shown in Fig. 1 without dotted lines). The latent variable is a factor derived from EFA. The observed variable is a response of the questionnaire items grouped into a factor showing high factor loading in EFA. The error variable is a factor other than those analyzed in EFA.

In this model, at first, each observed variable was connected by one latent variable and one error variable (Solid lines in Fig. 1). For example, a latent variable; "Education and cooperative structure on safety", connected to 5 observed variables showed high factor loading in EFA, and the observed variables are connected by each own error variable (e01- e05) in Fig. 1. CFA was conducted on this model; however, adequacy of the model to the obtained data resulted in improper solution. This is attributed to the fact that observed variables could be explained both by one latent variable showed the highest factor loading for each in EFA and by other latent variables showed relatively high factor loading. Therefore, the model was modified according to the factor loadings; other contributions of latent variables with high factor loading (0.25 or more) in descending order were added in the model, and then 5 new models created (Revised models 1 to 5). For instant, in Revised model 1, contribution that from "Education and cooperative structure on safety" to "**Q14:** I experiment at night by myself" was added to the first model.

To evaluate models in CFA, comprehensive evaluation by several fit indices is recommended. Comparative Fit Index (CFI) was used for evaluating the good fit of models. Since the data of this study had missing values, CFI which can estimate missing values was adopted to this study instead of Goodness of Fit Index (GFI) or Adjusted Goodness of Fit Index (AGFI). CFI should be more than 0.95, and the obtained value in Revised model 4 and 5 were actually satisfied (0.966). When the values of CFI in several models are almost the same, the model that shows the smallest value of Akaike's Information Criterion (AIC) is adopted for an optimum model. In addition, Root Mean Square Error of Approximation (RMSEA) is an index of distribution gap between a model and real data. The RMSEA resulted in 0.036 in the two models, which was within ≤ 0.05 and therefore considered a good fit (Steiger, 1989; Browne and Mels, 1990). In this study, Revised models 4 and 5 showed the highest value of CFI and the lowest value of RMSEA and χ^2/df. The value of AIC of Revised model 4 was lower than that of Revised model 5. Comparison of these evaluations concluded that Revised model 4 was the best fit to the obtained data (Fig.1 shows Revised model 4). Technically, the *p*-value should be greater than 0.05; however, the χ^2 value in practice is directly related to sample size (Doney and Cannon, 1997; Chen and Tsai, 2007) and frequently results in the rejection of a model that fits well. Therefore, the ratio of χ^2 over d*f*, which adjusts for the sample size, has been recommended as a better measure of good-of-fit (Hair et al., 2006; Kline, 1998; O'Connor, 2004). In fact, the values in this model indicated $p < 0.014$ and χ^2 (N= 406) = 67.019 which meant a poor fit. Then, we obtained χ^2/df=1.523, which a better level of the χ^2/df ratio is <3.0. (Table 4 shows the above evaluation indices.)

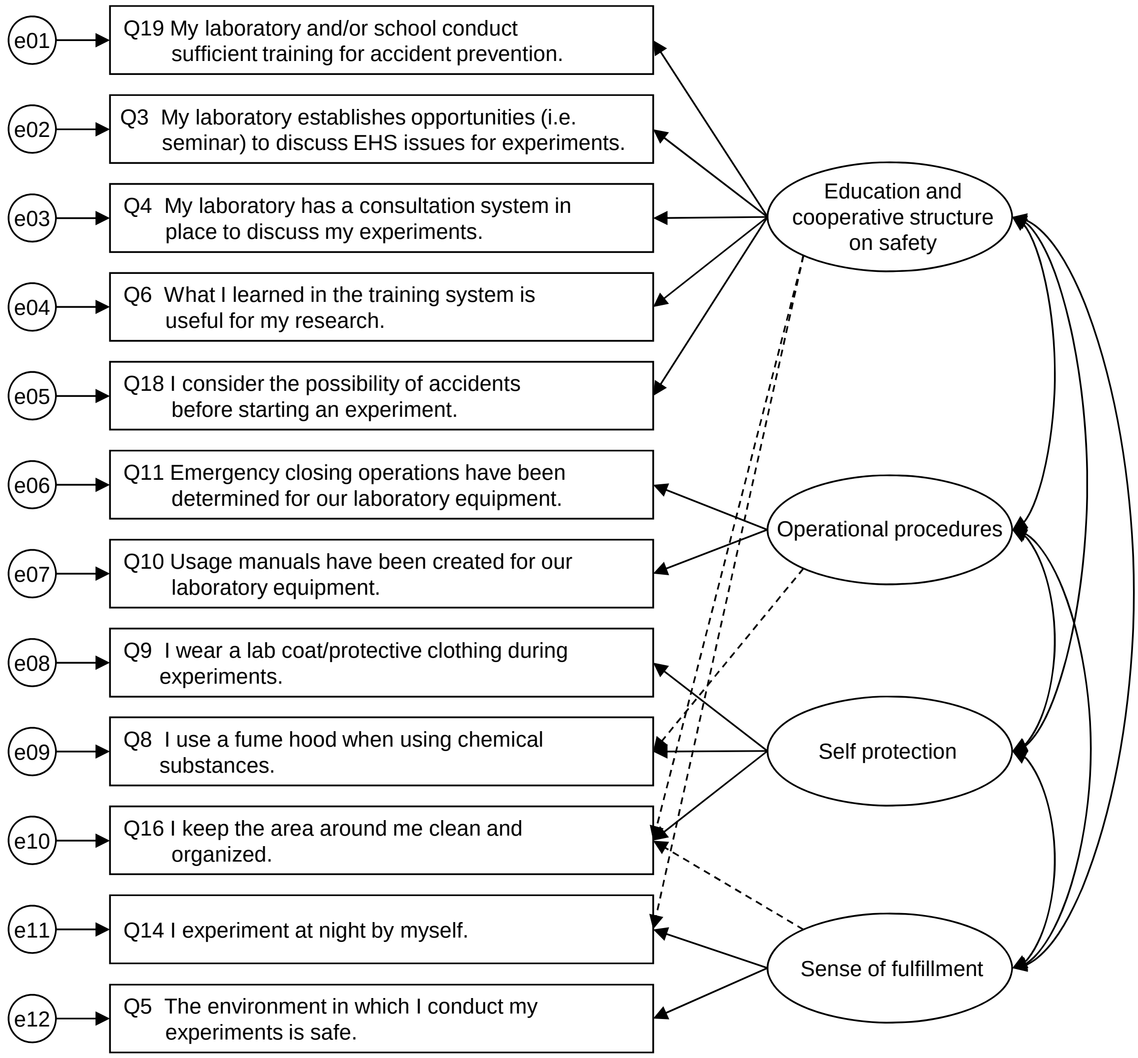

Fig. 1 Analyzed model (Revised model 4) in CFA.

Right: Ellipse shapes describe the extracted factor in EFA,
Middle: Rectangle shapes describe instrument items,
Left: Round shapes describe error variables in CFA

In conclusion, given that some contributions from a factor to a questionnaire item which showed relatively high factor loading in EFA, the hypothesis that responses of the questionnaire items were explained by the grouped-into-factor could be verified.

Table 4 Evaluation models by fit indices in CFA

Revised model	CFI	AIC	RMSEA	χ^2/df
1	0.903	198.256	0.059	2.388
2	0.944	171.971	0.045	1.825
3	0.942	173.944	0.046	1.865
4	0.966	159.019	0.036	1.523
5	0.966	161.019	0.036	1.523

Model fit CFI: Comparative Fit Index, AIC: Akaike's Information Criterion, RMSEA: Root Mean Square Error of Approximation, χ^2: Chi-square, *df*: Degree of freedom

3.4 Correlation analysis

The relationship between the extracted 4 factors and the 2 questionnaire items about safety awareness (**Q1** and **Q2**) was assessed by Pearson's correlation. Table 5 shows the coefficient of correlation above. Generally, the coefficient of correlation between 0.4 and 0.7 indicates a moderate correlation. The coefficient of correlation between the item "**Q1:** My university focuses on environment and safety of student doing experiment" showed a moderate correlation with the factor "Education and cooperative structure on safety". On the other hand, the item "**Q2:** My laboratory conscious of environment and safety" and the 4 factors, a moderate correlation was found with the 3 factors; "Education and cooperative structure on safety", "Operational procedures", and "Sense of fulfillment". Therefore, it could be explained that safety awareness in universities was comprehended by safety education and structure for cooperation on safety. It is associated with the fact that universities organize safety training programs and have the division of safety. Students recognize the attitude of universities on safety matters by attending the programs and seeing how the people of the safety division work. Meanwhile, safety awareness in scientific research laboratories was comprehended by issues on safety education and cooperation, experimental operation, and actual feeling. This reason seems that students have closer ties to research laboratories than to universities. There are some ways of safety education (such as on-the-job training on safety by laboratory staff or senior students, lectures on laboratory safety in the specific field which is the focus of each laboratory, informal rules on laboratory safety which are created by each research laboratory), operational procedure manuals of equipment, and real experimental works in research laboratories; therefore, these activities seem to influence safety awareness in research laboratories. Thus, the activities of universities and research laboratories influence safety awareness in each of them.

Table 5 Pearson's correlation between the questionnaire items (1, 2) and the extracted 4 factors

	Factor			
	1	2	3	4
Q1 My university focuses on environment and safety of student doing experiment.	.511	.374	.134	.276
Q2 My group is conscious of environment and safety.	.633	.513	.261	.415

4. CONCLUSION

This study revealed that the reality of the scientific university research laboratory, and that the subconscious attitudes on safety are composed of factors in the mind of experimenters in Japanese university research laboratories. Four factors were extracted by using the EFA statistical method on collected questionnaire data: "Education and cooperative structure on safety" (5 items, $\alpha = 0.656$), "Operational procedures" (2 items, $\alpha = 0.629$), "Self protection" (3 items, $\alpha = 0.435$), and "Sense of fulfillment" (2 items, $\alpha = 0.254$). CFA was conducted to verify the hypothesis that the observable variances (the responses of the questionnaire items) could be explained by the unobservable variances (the factors). This analysis indicated that the observed variables could be explained by adding other latent variables and showed relatively high factor loading in EFA, usually explained by one latent variable showing the highest factor loading for each item in it though. Modified models (Revised models 1- 5) were created and comparison of evaluations among the models concluded that Revised model 4 was the best fit to the obtained data (CFI= 0.966, AIC= 159.019, RMSEA= 0.036, χ^2 (N= 406) = 67.019, $p < 0.014$, and χ^2/df =1.523). EFA also showed that safety awareness in universities and scientific research laboratories are comprehended by some of the extracted factors in this study through the examination of the relationships among safety awareness and subconscious factors. The latent factor "Education and cooperative structure on safety" is positively correlated with the safety awareness in universities and scientific research laboratories respectively. The safety awareness in scientific research laboratories has a moderate correlation with the factors "Operational procedures" and "Sense of fulfillment" as well. From the results, it is assumed that safety awareness in universities was recognized by safety training programs organized by universities. On the other hand, scientific research laboratories have a closer relationship to students so that students' near affairs seem to have influences.

Through this study, it was indicated that the extracted factors affected safety awareness and that subconscious views on safety seem to help explain behavior in university research laboratories. The results of this study would undoubtedly prove useful in the development of effective educational methods and management systems.

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